FDCD WORKING PAPER

A PRELIMINARY WEATHER-CROP YIELD MODEL FOR SOVIET GRAIN

Valentine Zabijaka
January 1974

Foreign Demand and Competition Division

Economic Research Service

U.S. Department of Agriculture

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Introduction

Much research has been directed toward the problem of relating crop yields to weather. The value of a model that would show the effect of weather factors, such as temperature and precipitation, on the yield of a specific crop can be easily justified. Perhaps the most important use of a predictive weather-crop yield model would be in evaluating the potential production of a given crop.

The analysis that follows is a brief review of preliminary research aimed at estimating the effects of weather (temperature, precipitation, and soil moisture), fertilizer use, and, in some instances, time on wheat yields in the USSR. Regression analysis was used to determine weather variables that significantly influence crop yields. The resulting regression equations are used to "predict" wheat yields in the USSR for 1972 and 1973. Basic research was completed in August 1973. Minor revisions include incorporation of data on plan fulfillment, published in January 1974.

Procedures

Data: Weather regions of the USSR (see map) were selected as basic geographical areas for computational purposes. The 27 weather regions do not cover the USSR but do include about 90 percent of total wheat production. Final estimates of total USSR wheat production were adjusted to include the residual production, that is, the 10 percent in areas outside the weather regions.

Data on average precipitation and temperature were available for each weather region and could be used as given. Data on production and yields of winter and spring wheat are derived from official Soviet statistics for crop regions (which in several instances correspond to weather regions) and oblasts. Computations were based on the dominant type of wheat grown in the given weather region. In a few regions, such as those in the Volga basin, computations were performed for both types. Data for the time period 1960-71 were used to estimate weather-yield relationships.

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*Based on a paper presented by Valentine Zabijaka, formerly Economic Research Service, U.S. Department of Agriculture, at a Seminar sponsored by the Foreign Demand and Competition Division, Economic Research Service, September 14, 1973. Mr. Zabijaka is now with the U.S. Department of Commerce.

Variables: The following independent variables were used in constructing the regression equations:

(1) Precipitation - Total precipitation during a month in millimeters.

(2) Soil moisture - Estimated by a simplified Thornthwaite formula for the last day of each month.

(3) Temperature - The simple monthly average of daily mean temperatures.

(4) Fertilizer - Statistical data is available on total chemical fertilizer used in a given republic; no data is available on fertilizer application to individual crops,or by region.

(5) Time - In a few regions time, in years was used as a variable in place of fertilizer. Fertilizer use and time are closely correlated.

Regression techniques: Step-wise multiple linear regression was used, with computer selection of variables. The independent variable first entered in the computation was selected on the basis of highest correlation with the dependent variable (yield). Subsequent independent variables were entered according to the extent to which they explain the residual fluctuations in the dependent variable. Only those variables with significant t-values are included in the final equation. A weather-yield equation was directly estimated for each weather region.

Results

Wheat yield regression equations for the 27 USSR weather regions are shown in Table 1. "Predictions" of Soviet wheat yields in each region for 1972 and 1973 are shown in Table 2. Explanatory notes follow each table.

Fit of the equations (Table 1) appears to be good. Coefficients of determination (R^2) are high; 21 are .85 and above. Relatively poor fits were obtained for two regions (South Urals and West Kazakhstan). By omitting 1965, a poor year, much better fits are obtained. Both alternatives are shown. It is recognized that the good fit of the regression equations may be, in part, a result of the limited number of years of data in relation to the number of independent variables used, i.e. a small number of degrees of freedom.

Fertilizer appears to be an important explanatory factor in nearly all of the winter wheat regions but in only one or two of the spring wheat regions.

A time trend term was used in one spring wheat region (West Siberia). Time trends could have been used in other regions instead of fertilizer as the two factors are closely correlated. Fall soil moisture (October or November) appears to be the most important weather-type variable in the winter wheat equations, while June conditions (soil moisture, precipitation, and temperature) explained more of the yield variation in the spring wheat regions.

Using the regression technique indicated, an overall USSR winter wheat yield 27.3 quintals per hectare* (40.6 bushels per acre) was predicted for 1973. This can be compared to overall USSR winter wheat yields (derived from Soviet statistics) ranging from 12.9 to 23.1 quintals per hectare (19.2 to 34.3 bushels per acre) during 1960-71. Using regression techniques, an overall yield of 11.2 quintals per hectare (16.7 bushels per acre) was predicted for spring wheat in 1973.** The predicted yield of spring wheat is within the range of overall USSR spring wheat yields, which in the 1960-71 period ranged from 5.5 to 12.2 quintals per hectare (8.2 to 18.1 bushels per acre).

Total USSR wheat production for 1973, based on the previously described regression technique and incorporating preliminary and revised area estimates is shown below.

	Preliminary		Revised		
	Area Mil. ha.	Prod. Mil. tons	Area Mil. ha.	Yield Quintals/ha.	Prod. Mil. tons
Winter wheat	16.0	43.7	18.3	26.2	48.0
Spring wheat	46.5	52.0	44.7	13.8	61.7
	62.5	95.7	63.0	17.4	109.7 1/

1/ Official Soviet figure.

Research is continuing and efforts will be made to refine the regression equations through input of new data and use of other regression and statistical techniques.

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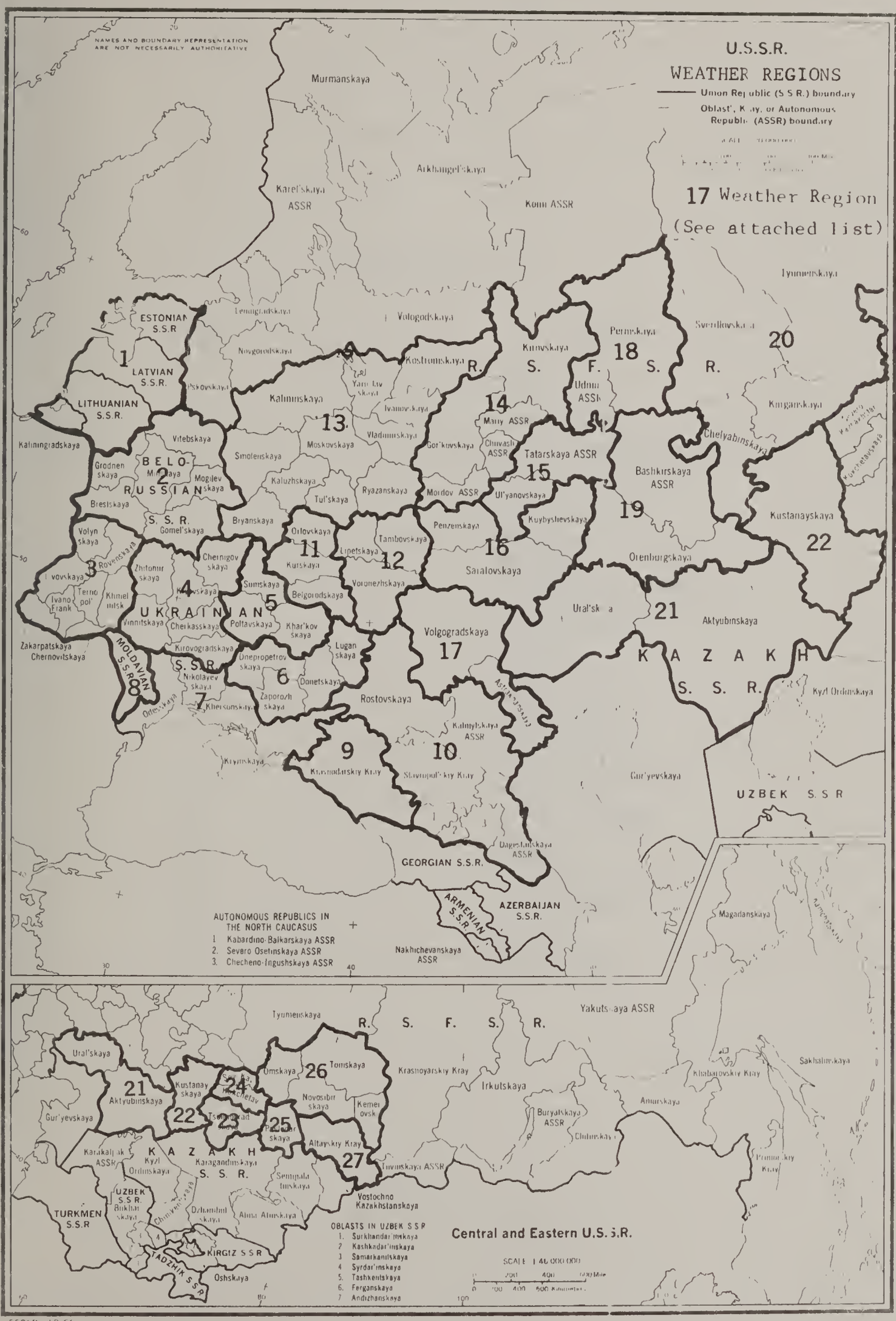
*Conversion equivalents: One metric quintal (centner) = 220.46 pounds
One hectare = 2.471 acres
To convert metric quintals (centners) of wheat per hectare to bushels per acre, multiply by 1.487.

**A yield of 9.7 quintals per hectare would result if alternative equations omitting 1965 data were used for the South Urals and West Kazakhstan regions.


NAMES AND BOUNDARY REPRESENTATION ARE NOT NECESSARILY AUTHORITATIVE
U.S.S.R.
WEATHER REGIONS
Union Republic (S.S.R.) boundary
Oblast', Kray, or Autonomous Republic (ASSR) boundary
17 Weather Region
(See attached list)
1 ESTONIAN S.S.R.
LATVIAN S.S.R.
LITHUANIAN S.S.R.
2 BELO-RUSSIAN S.S.R.
3 UKRAINIAN S.S.R.
4
5
6
7
8 MOLDAVIAN S.S.R.
9
10
11
12
13
14
15
16
17
18 R. S. F. S. R.
19
20
21
22
Murmanskaya
Arkhangel'skaya
Karel'skaya ASSR
Komi ASSR
Leningradskaya
Vologodskaya
Novgorodskaya
Pskovskaya
Kostromskaya
Kirovskaya
Permskaya
Sverdlovskaya
Tyumenskaya
Udmu ASSR
Kaliningradskaya
Kalininskaya
Yaroslavskaya
Ivanovskaya
Mariy ASSR
Kurganskaya
Vitebskaya
Smolenskaya
Moskovskaya
Vladimirskaya
Gor'kovskaya
Chuvash ASSR
Tatarskaya ASSR
Chelyabinskaya
Grodnenskaya
Mogilevskaya
Kaluzhskaya
Ryazanskaya
Mordov ASSR
Ul'yanovskaya
Bashkirskaya ASSR
Brestskaya
Gomel'skaya
Bryanskaya
Tul'skaya
Penzenskaya
Kuybyshevskaya
Kustanayskaya
Volynskaya
Rovenskaya
Orlovskaya
Tambovskaya
Lipetskaya
Chernigovskaya
Kurskaya
Orenburgskaya
Saratovskaya
Zhitomirskaya
Sumskaya
Voronezhskaya
Ivano Frankovskaya
Ternopol'
Khmel'nitsk
Belgorodskaya
Ural'skaya
Aktyubinskaya
Vinnitskaya
Cherkasskaya
Poltavskaya
Khar'kovskaya
Volgogradskaya
Zakarpatskaya
Chernovitskaya
Kirovogradskaya
Lugan skaya
Oneropetrovskaya
Nikolayevskaya
Donetskaya
Zaporozh skaya
Odesskaya
Khersonskaya
Rostovskaya
Astrakhanskaya
Kalmytskaya ASSR
Krymskaya
Krasnodarskiy Kray
Stavropol'skiy Kray
Gur'yevskaya
Kyzl Ordinskaya
UZBEK S.S.R.
Dagestanskaya ASSR
GEORGIAN S.S.R.
ARMENIAN S.S.R.
AZERBAIJAN S.S.R.
Nakhichevanskaya ASSR
AUTONOMOUS REPUBLICS IN THE NORTH CAUCASUS
1 Kabardino-Balkarskaya ASSR
2. Severo Osetinskaya ASSR
3. Checheno-Ingushskaya ASSR
Yakutskaya ASSR
Magadanskaya
Krasnoyarskiy Kray
Irkutskaya
Khabarovskiy Kray
Sakhalinskaya
Amurskaya
Buryatskaya ASSR
Chitinskaya
Primorskiy Kray
Tuvinskaya ASSR
Tomskaya
Omskaya
Novosibirskaya
Kemerovskaya
Altayskiy Kray
Karakalpak ASSR
Karagandinskaya
Semipalatinskaya
Vostochno Kazakhstanskaya
TURKMEN S.S.R.
Chimkentskaya
Dzhambul skaya
Alma Atinskaya
KIRGIZ S.S.R.
TADZHIK S.S.R.
Oshskaya
OBLASTS IN UZBEK S.S.R.
1. Surkhandar'inskaya
2. Kashkadar'inskaya
3. Samarkandskaya
4. Syrdar'inskaya
5. Tashkentskaya
6. Fergan skaya
7. Andizhanskaya
Central and Eastern U.S.S.R.
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Weather Regions

Number	Name
1	Baltic
2	Belorussia
3	West Ukraine
4	North Central Ukraine
5	Northeast Ukraine
6	East Ukraine
7	South Ukraine
8	Moldavia
9	Krasnodar
10	Northeast Caucasus
11	West Blacksoil
12	East Blacksoil
13	Central
14	Volga-Vyatsk
15	Upper Volga
16	Middle Volga
17	Lower Volga
18	Northwest Urals
19	South Urals
20	Northeast Urals
21	West Kazakhstan
22	Kustanai
23	Tselinograd
24	North Kazakhstan
25	Pavlodar
26	West Siberia
27	Altai Krai

TABLE 1

WHEAT YIELD REGRESSION RUNS FOR THE USSR WEATHER REGIONS

USSR Weather Regions	Wheat type	Regression equation (independent variables in order of their entry)	Calculated		Observed wheat yields (1960-71)	
			R^2	S.E.	Mean centner/hectare	S.D.
1. Baltics .7%	WW	Yield= .589 + . 157 FT+ .066SNOV - 1.074TMAY	.91	2.3	16.7	6.6
2. Belorussia 1.0%	WW	Yield= 8.012 + .092FT - .04PJUL	.92	1.3	13.2	4.2
3. W. Ukraine 3.2%	WW	Yield= 16.574 + .169FT - .695TNOV	.83	1.9	20.9	4.3
4. N.C. Ukraine 6.2%	WW	Yield= 15.994 + .069SOCT - 1.567TNOV+ .132FT	.89	2.1	21.4	5.5
5. N.E. Ukraine 3.8%	WW	Yield= 37.059 + .128SNOV + .109FT - 1.791TJUL + .545TAPR	.93	1.9	21.2	5.8
6. E. Ukraine 3.4%	WW	Yield= -2.282 + .108SNOV + .153FT- .108PAPR + .06SMAR + +.155SSEP -.079SOCT	.88	2.3	20.9	4.6
7. S. Ukraine 5.6%	WW	Yield=53.007+ .172FT - 2.245TJUN + .09PMAY	.93	1.7	21.5	5.3
8. Moldavia .7%	WW	Yield=10.645 + .12SOCT + .201FT- .055PJUL + .065PMAY- - .624TNOV	.97	1.5	18.5	6.2
9. Krasnodar 5.6%	WW	Yield= 81.388 + .435FT - 3.77TJUN + .084SNOV +.044PJUN	.90	2.3	27.1	5.6
10. N.E. Caucasus 12.8%	WW	Yield =-2.944+ .361TAPR + .16SNOV + 2.604TNOV -.132SOCT	.80	2.1	15.8	3.7
11. W. Blacksoil 1.6%	WW	Yield= 3.186 + .025SNOV + .345FT + .111PMAY- .663TNOV	.86	2.5	17.5	5.3
12. E. Blacksoil 2.5%	WW	Yield= 24.024 + 1.395TAPR - 1.475TMAY + . 151 FT	.92	1.2	16.2	3.6
13. Central 1.7%	WW	Yield=73.935 + .266FT -.361SMAR + .039SJUN	.88	1.2	12.0	3.0
" .9%	SW	Yield= 19.98 + .415FT + .066SAUG - .096PJUL - .919TJUL	92	1.4	10.7	4.0

TABLE 1 WHEAT YIELD REGRESSION RUNS FOR THE USSR WEATHER REGIONS

USSR Weather Regions	Wheat type	Regression equation (independent variables in order of their entry)	Calculated		Observed wheat yields (1960-71)	
			R_2	S.E.	Mean	S.D.
					centner/hectare	
14. Volga-Vyatsk .4%	WW	Yield=-54.901 + .113FT + .201SJUN + 2.297TAUG + .496TMAY	.85	1.8	11.8	3.7
" .7%	SW	Yield=-43.55+.157FT+ .059PJUN + 2.212TAUG + .105 SJUN	.94	1.0	9.6	3.4
15. Upper Volga 2.3%	SW	Yield= 55.98 + .199FT - .527TJUN - 949TJUL- .09SMAY- -.762TMAY + .08PAPR	.90	1.6	13.0	3.4
16. Middle Volga 4.6%	SW	Yield=-11.826 + .191SAUG + .908TMAY + .056PJUN	.90	.9	10.2	2.5
17. Lower Volga 2.2%	WW 1/	Yield= 127.839 + 2.34TAPR -.05SOCT - 4.599TMAY- .171SJUN + +.13SMAR-2.725TJUL-.263PJUL	.86	2.5	14.5	4.1
"	SW 1/	Yield= 40.097 + .153SMAY- 2.872TJUN + .266PJUN - .135FT	.73	2.3	8.9	3.5
18. N.W. Urals .5%	SW	Yield=-11.583 + .076PJUL + .813TJUL	.80	1.0	8.8	1.9
19. S. Urals 5.9%	SW	Yield= 72.454 - 3.484TJUN - .984TJUL+ .981TAUG	.62	2.4	11.3	3.3
(" 2/5.9%	SW	Yield= 80.153 - 3.732TJUN + .078TJUL - .228PAUG+ + .196PAPR- .18FT	.91	1.4	11.7	3.1)
20. N.E. Urals 4.6%	SW	Yield= 1.362 - 1.834TJUN - .018PJUL - .056PAUG + .02SJUN + +.279FT + 2.433TAUG	.97	.9	12.7	3.4
21. W. Kazakhstan 1.3%	SW 3/	Yield= 58.63 - 2.591TJUN	.42	3.4	6.8	4.1
(" 2/ 1.3%	SW 3/	Yield= 102.124 - 4.584TJUN + .264SJUL - .205SJUN	.91	2.0	7.3	4.3)
22. Kustanai 3.1%	SW 3/	Yield= 30.189 - 2.699TJUN + .156PJUL + . 934TJUL	.85	1.6	8.2	2.9

1. Assumed yield. No yield data available by type of wheat
2. Regression equation without 1965 data.
3. Data for selected years: 1960,1961,1965-68, and 1971.

WHEAT YIELD REGRESSION EQUATIONS FOR THE USSR WEATHER REGIONS

USSR Weather Regions	Wheat type	Regression equation (independent variables in order of their entry)	Calculated		Observed wheat yields (1960-71)	
			R^2	S. E.	Mean	S.D.
					centner/hectare	
23. Tselinograd 2.1%	SW 3/	Yield= 19.602 + .072SJUN - .962TJUN	.72	1.7	6.7	2.6
.Kazakhstan 4.0%	SW 3/	Yield= 30.535 + .084PJUN - .837TMAY - .893TJUN	.91	1.1	8.0	2.7
. Pavlodar .9%	SW 3/	Yield= -24.629 - .023SJUN + 1.433TAUG +.192PMAY	.96	.8	5.6	2.9
6. W. Siberia 5.9%	SW	Yield=-540.604 +. .145SJUN - .115PAUG + .275TIME + +.035PJUL	.87	1.6	9.3	3.6
7. Altai Krai 5.7%	SW	Yield= 3.767 + .097SMAY - .745TJUL+ .046PJUL + .403TMAY	.92	1.2	9.4	3.4

Table 1: Explanatory Notes

Column

Remarks

1 "USSR Weather Regions": As shown on map. Regions delineate areas with similar soil, crop, and weather characteristics. The percentage figure indicates the relative importance of the region in terms of its wheat production (1971).

2. "Wheat type": Winter wheat (WW) and spring wheat (SW). The dominant type of wheat grown in each region is noted. (Both types are shown for some regions.)

3. "Regression equation": The yield regression equations are expressed in quintals per hectare. Independent variables are shown in the order of their entry into the regression equation. The following independent variables were used:

a. Temperature ("T", followed by the abbreviation of the month)--The simple monthly average of daily mean temperatures (Celsius, to one decimal place).

b. Precipitation ("P", followed by the abbreviation of the month)--The total precipitation during a month in millimeters.

c. Soil moisture ("S", followed by the abbreviation of the month)--Estimated by a simplified Thornthwaite formula for the last day of the month.

d. Fertilizer ("FT")--Based on the estimated amount of fertilizer used per hectare of cultivated land (kilograms per hectare).

e. Time ("TIME")--Annual trend used in place of fertilizer in a few regions. Fertilizer use and time are closely correlated.

4. "R^2": Coefficient of determination. Expresses the percent of total fluctuations in wheat yield explained by the regression equation.

5. "S.E." [S.E.E.]: Standard error of estimate. Measures the accuracy of estimates obtained through the use of the regression equation (68% of all cases lie within $\pm$ one standard error of estimate; 95% within $\pm$2 S.E.E.; 99.7% within $\pm$3 S.E.E.). The S.E.E. refers to estimates within the time period of the regression; the expected error of forecast yields would be greater.

6. "Mean": Observed average wheat yield in the given weather region during the study period (usually 1960-71).

7. "S.D.": Standard deviation, a measure of variation around the observed mean, similar to the standard error of estimate (68% of all cases lie within a range of $\pm$ one standard deviation, and so on).

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Wheat yield projections for the weather regions of the USSR (using regression equations)

USDA-ERS

(Quintals/Hectare)

(corrected 9/14)

Weather region	Type of wheat	Projection 1972	Projection 1973	R^2	Standard error	1960 - 1971 range	Average yield $\bar{x}$	Standard deviation	Comments
Baltics	WW	25.5	31.6	.91	2.3	8.1 - 26.1	16.7	6.6	Record 1973
Byelorussia	WW	20.8	21.3	.92	1.3	7.6 - 21.8	13.2	4.2	
W. Ukraine	WW	28.5	27.2	.83	1.9	15.8 - 28.2	20.9	4.3	Record 1972
N.C. Ukraine	WW	31.1	26.8	.89	2.1	13.6 - 31.5	21.4	5.5	
N.E. Ukraine	WW	27.6	38.5	.93	1.9	9.9 - 31.6	21.2	5.8	Record 1973
E. Ukraine	WW	22.7	32.8	.88	2.3	11.6 - 27.6	20.9	4.6	Record 1973
S. Ukraine	WW	21.2	33.9	.93	1.7	14.5 - 31.1	21.5	5.3	Record 1973
Moldavia	WW	31.9	33.2	.97	1.5	9.2 - 28.2	18.5	6.2	Records 1972-3
Krasnodar Krai	WW	18.0	42.0	.90	2.3	19.4 - 37.1	27.1	5.0	Record 1973
N.E. Caucasus	WW	22.1	25.2	.80	2.1	10.4 - 21.1	15.8	3.7	Records 1972-3
W. Black Soil	WW	24.2	32.0	.86	2.5	7.7 - 24.9	17.5	5.3	Record 1973
E. Black Soil	WW	20.1	23.9	.92	1.2	8.3 - 22.0	16.2	3.6	Record 1973
Central	WW	16.6	18.0	.88	1.2	7.7 - 16.5	12.0	3.0	Records 1972-3
" "	SW	14.3	19.6	.92	1.4	[illegible]	10.7	4.0	Record 1973
Volga-Vyatsk	WW	26.9	8.2	.85	1.8	7.7 - 19.0	11.8	3.7	Record 1972
" "	SW	25.7	8.8	.94	1.0	5.6 - 15.9	9.6	3.4	Record 1972
Upper Volga	SW	17.8	19.1	.90	1.6	9.2 - 19.0	13.0	3.4	Record 1973
Middle Volga	SW	5.9	16.5	.90	0.9	6.8 - 14.9	10.2	2.5	Record 1973
Lower Volga	WW	12.5	6.8	.86	2.5	7.5 - 23.1	14.5	4.1	
" "	SW	1/	20.3	.73	2.3	4.8 - 17.7	8.9	3.5	Record 1973
N.W. Urals	SW	8.7	8.6	.80	1.0	6.0 - 12.3	8.8	1.9	
S. Urals	SW	13.8	7.7	.62	2.4	6.8 - 18.8	11.3	3.3	
" " 2/	SW	17.9	1/	.91	1.4	8.2 - 18.8	11.7	3.1	
N.E. Urals	SW	22.5	16.2	.97	0.9	7.1 - 19.1	12.7	3.4	Record 1972
W. Kazakhstan 3/	SW	7.8	5.5	.42	3.4	1.4 - 14.4	6.8	4.1	
" " 2/ 3/	SW	7.6	5.0	.91	2.0	1.4 - 11.4	7.3	1.2	
Kustanai 3/	SW	10.3	2.8	.85	1.6	3.9 - 13.2	8.2	2.9	
Tselinograd 3/	SW	9.3	7.8	.72	1.7	2.0 - 9.6	6.7	2.6	
N. Kazakhstan 3/	SW	12.3	9.5	.91	1.1	2.8 - 11.3	8.0	2.7	Record 1972
Pavlodar 3/	SW	1.4	2.9	.96	0.8	1.3 - 9.1	5.6	2.9	
W. Siberia	SW	17.9	17.4	.87	1.6	3.5 - 14.6	9.3	3.6	Record 1972
Altai Krai	SW	15.5	12.9	.92	1.2	3.2 - 15.5	9.4	3.5	

1/Negligible
2/Regression equation without 1965
3/Data for selected years: 1960, 1961, 1965-8, and 1971

Table 2: Explanatory Notes

Column	Remarks
1	"Weather region": As shown on map. Regions delineate areas with similar soil, crop, and weather characteristics.
2	"Type of wheat": Winter wheat (WW) and spring wheat (SW). The dominant type of wheat grown in each region is noted. (Both types are shown for some regions.)
3,4	"Projection 1972, 1973": Yield projections for 1972 and 1973 in quintals per hectare.
5	"R^2": Coefficient of determination. Expresses the percent of total fluctuations explained by the regression equation.
6	"Standard error": Standard error of estimate (S.E.E.). Measures the accuracy of estimates obtained through the use of the regression equation (68% of all cases lie within $\pm$ one standard error of estimate; 95% within $\pm$2 S.E.E.; 97.7% within $\pm$3 S.E.E.). The S.E.E. refers to estimates within the time period of the regression; the expected error of forecast yields would be greater.
7,8	"1960-1971 range": Wheat yield range during the study period (usually 1960-71) in quintals per hectare.
9	"Average yield": Average (mean) wheat yield over the study period (usually 1960-71) in quintals per hectare.
10	"Standard deviation": A measure of variation around the average (mean) wheat yield, similar to the standard error of estimate (68% of all cases lie within a range of $\pm$ one standard deviation, and so on).
11	"Comments": Record yield projections noted.